MIXING, RHEOLOGY AND SLURRY HANDLING COURSE

Dr.Nigel Heywood – BHRG

Dr. Art Etchells – AWE3 entp.

January 14 and 15 2008

INTRODUCTIONS

The instructors

BACKGROUND

- Arthur Etchells
- BS and MS chemical engineering U of Pennsylvania
- PhD chemical engineering University of Delaware
- 2 years with Rohm and Haas
- 39 years with Dupont
- Last 29 years as an internal consultant

BACKGROUND

- Internal consultant in mixing and fluid flow in Dupont Engineering
- Served all businesses as a consultant
  - Manufacturing and process development and plant design
  - Polymers to slurries
  - Includes design of DWPF at SRS
- Retired in 2002 as Dupont Fellow – highest technical position in company
- Private consulting since
  - WTP at Hanford for Bechtel through Dupont

BACKGROUND

- Founding council member and former president and award winner of North American Mixing Forum an affiliate of the AIChE
- Adjunct teaching at University of Delaware and Rowan University
- Co-author of Handbook of Industrial Mixing Wiley 2002.

INTRODUCTIONS

The attendees

OTHER EXPERTS

- Professor David Boger – U of Melbourne
  - Rheology and slurry handling

- Dr. David Dickey – Mixtech – consultant on mixing processes and equipment

COURSE OUTLINE

- Two instructors – alternating
- Mixing and slurry flow
- Not often given this way
- Usually separate courses
- Lots of synergy
- Both topics demand same physical properties of the slurries
- Neither is covered in conventional engineering education

Mixing of Slurries

Arthur William Etchells III
AWE3 Enterprises
January 12 and 15 2008
DOE workshop

What will not be covered

- This is basically a 7 hour course
- Typical mixing courses are 3-4 days or 13 weeks
- Many things are being skipped
  - Gas liquid
  - Mass transfer
  - Heat transfer
  - Chemical reactions
  - High viscosity mixing – polymers
  - Workshops, sample calculations and problem solving

Ask questions anytime

Some time at end and during the rest of the workshop to ask questions and discuss problems

WHAT IS MIXING and WHY IT MATTERS

Introduction

M2

DEFINITION OF MIXING

The use of a mechanical device to generate a fluid motion to achieve a process result

DEFINITION OF MIXING

- Mechanical devices
  - There is a mixer
- Fluid motion
  - A branch of fluid mechanics
  - Will not discuss solids solids dry mixing
    - Does not depend on fluid mechanics or the Navier Stokes equations
- PROCESS RESULT
  - Mixing is a means to an end not an end itself.

PROCESS RESULTS

M3

PROCESS RESULTS

- Typical Duties/ Process Results
- Blending of miscible fluids
  - storage and blending
  - chemical reaction
    - high and low viscosity
- Contacting immiscible liquids
  - emulsification
  - extraction

PROCESS RESULTS

- Suspending Solids
  - reactors
  - precipitators
  - crystallizers
- Dispersing Solids
  - Slurry and product makeup
  - pastes

PROCESS RESULT

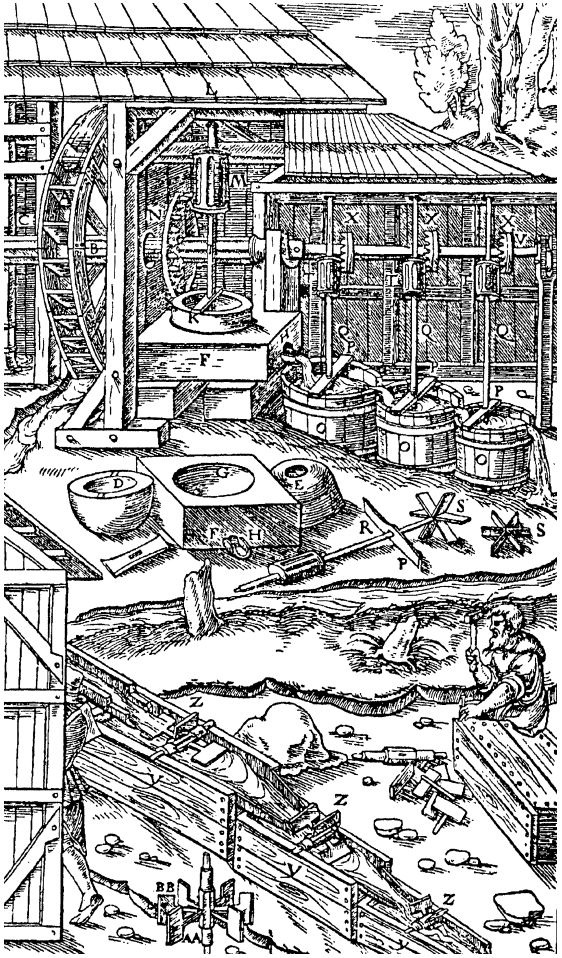
- Dispersing gases into liquids
  - reactors
  - fermentors
- Heating and cooling of liquids

- Other e.g. settled solids mobilization or gas release

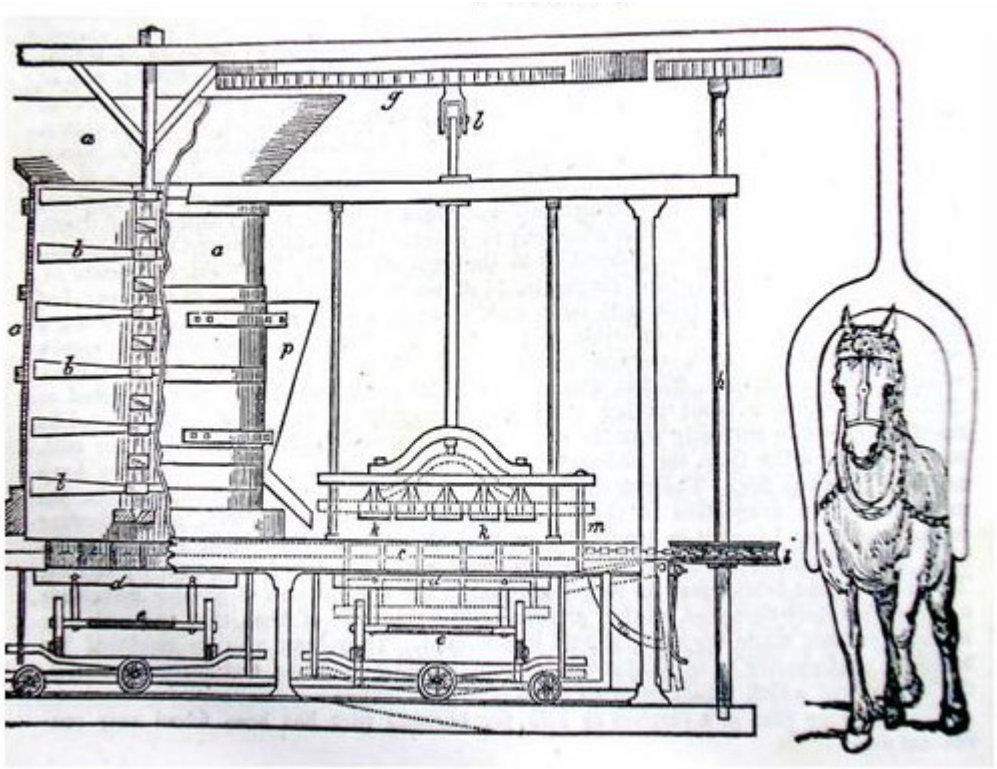
MIXING EQUIPMENT

EARLY MIXING

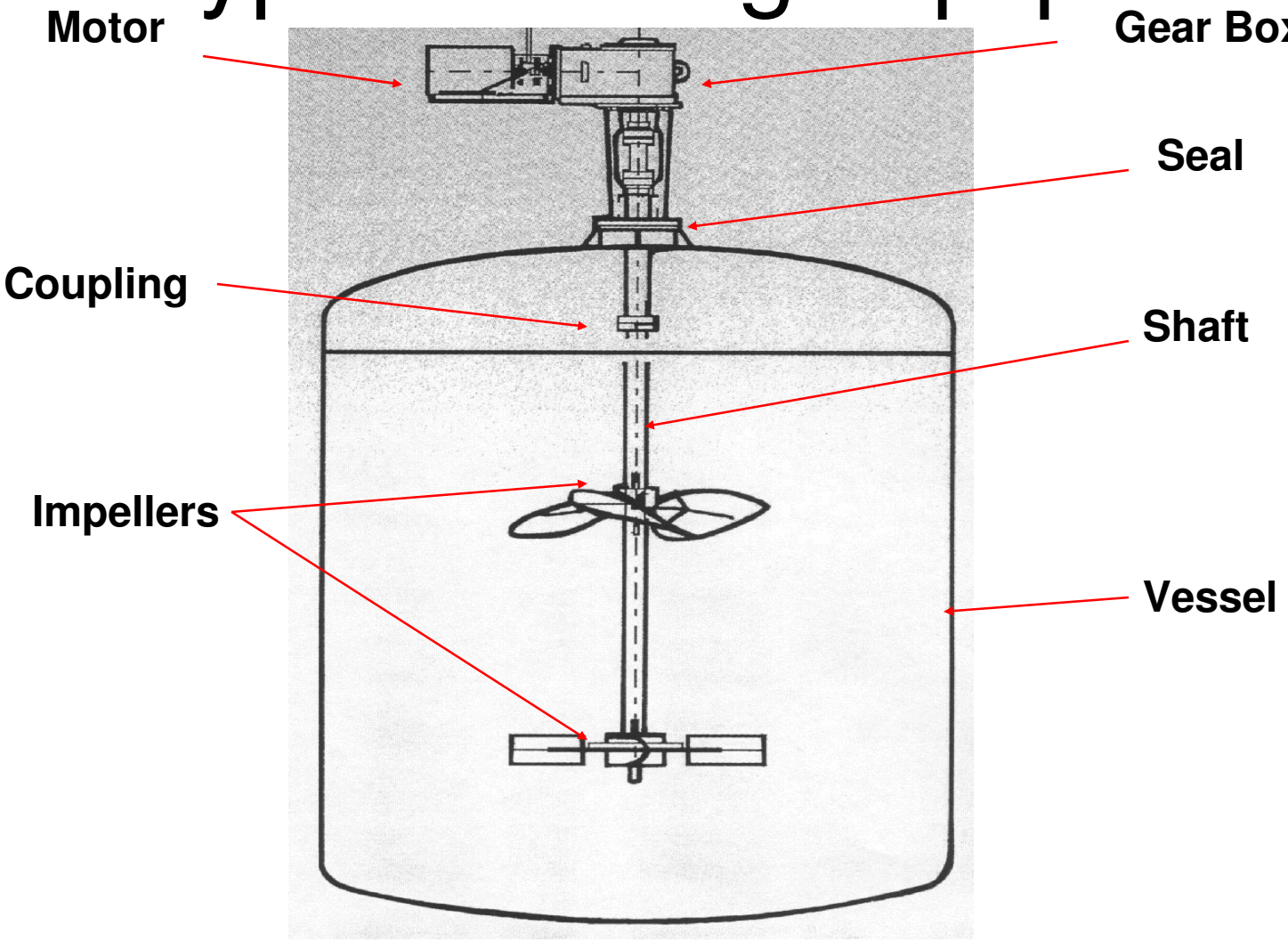
MODERN MIXING



ONE HORSEPOWER



Typical Mixing Equipment



MIXING EQUIPMENT types

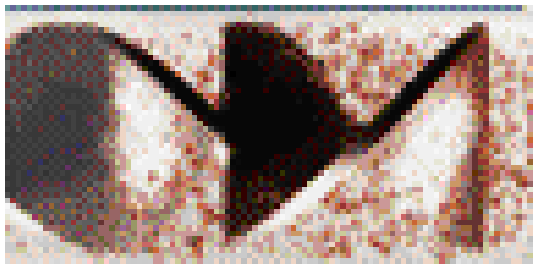
- Mechanical agitators in vessels
  - vertical
  - angled or side mounted
- Horizontal
  - side entering - mechanical
  - jets
- Gas mixed

MIXING EQUIPMENT types

- Pipelines
  - motionless mixers
  - mechanical
- High Speed Dispersers
  - blades
  - rotor stator
  - in line and in tank
- Extruders

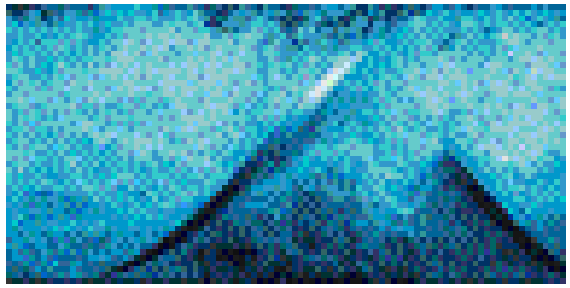
Motionless Mixers

Turbulent Blending



Liquid-liquid dispersion

Laminar Blending



Gas-liquid dispersion

Dynamic In-line Mixers

An inefficient pump

COMMENT ON PICTURES

- Many pictures developed by Computational Fluid Dynamics – a mathematical solution to the equations of motion presented visually
- CFD can produce pictures that are very hard to get experimentally
- Not all CFD gives correct pictures as will be discussed later on
- When we show CFD pictures they will be correct and better than anything experimental
- LDA gives similar pictures but experimental

MIXING EQUIPMENT

- VESSELS
- Right cylinders
  - Z/T = 1.0
- Ponds and lagoons
  - Z/T <<<<<< 1.0

MIXING EQUIPMENT impellers

- Propellors
- Paddles
- Turbines D/T 0.25 to .60
  - flat blades - Rushton turbines with disk
  - angled blades
  - hydrofoils
- Anchors D/T 0.9 to 0.95
- Helical Ribbons and Screws D/T .95-.98

RADIAL IMPELLERS

* RUSHTON
* CD-6 SMITH
* CHEMINEER -B-6

EVOLUTION OF THE HYDROFOIL

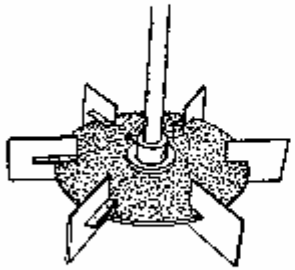
PROPELLOR

PBT - A200 - MFT - etc.

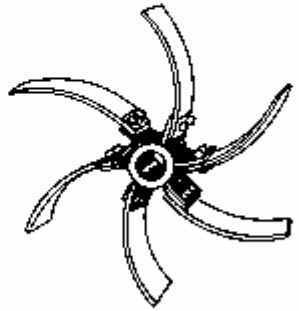
A310

A420

Radial Flow Impellers

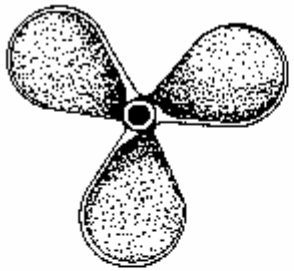


Disk Style Flat Blade Turbine
Commonly Referred to as
the Rushton Impeller

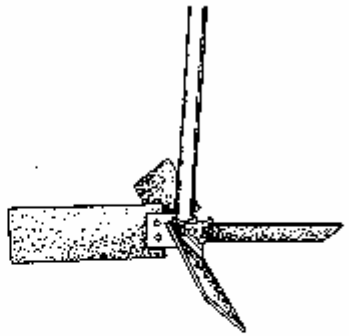


Sweptback or Curved Blade Turbine
(a Spiral Turbine)

Axial Flow Impellers



Propeller



45° Pitched Blade Turbine

Figure 1.4 Turbulent impellers.

IMPELLER CHARACTERISTICS

- Describe impellers by a set of numbers
- Power Number
- Flow Number
- Zweitering constant for solids suspension
- Cavitation number for gas liquid
- Etc.
- These numbers often involve tank geometry parameters in addition

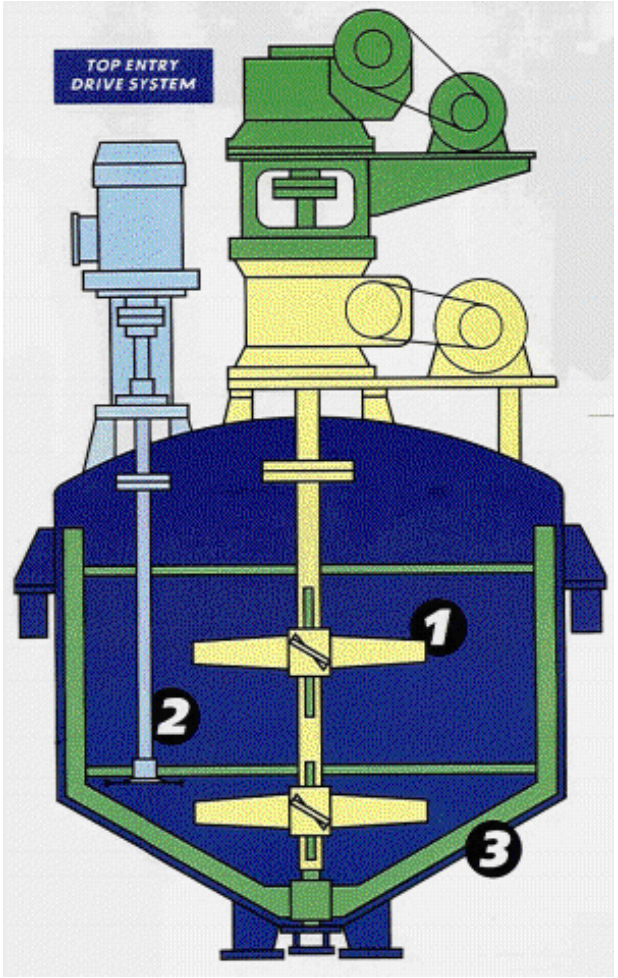
IMPELLER CHARACTERISTICS

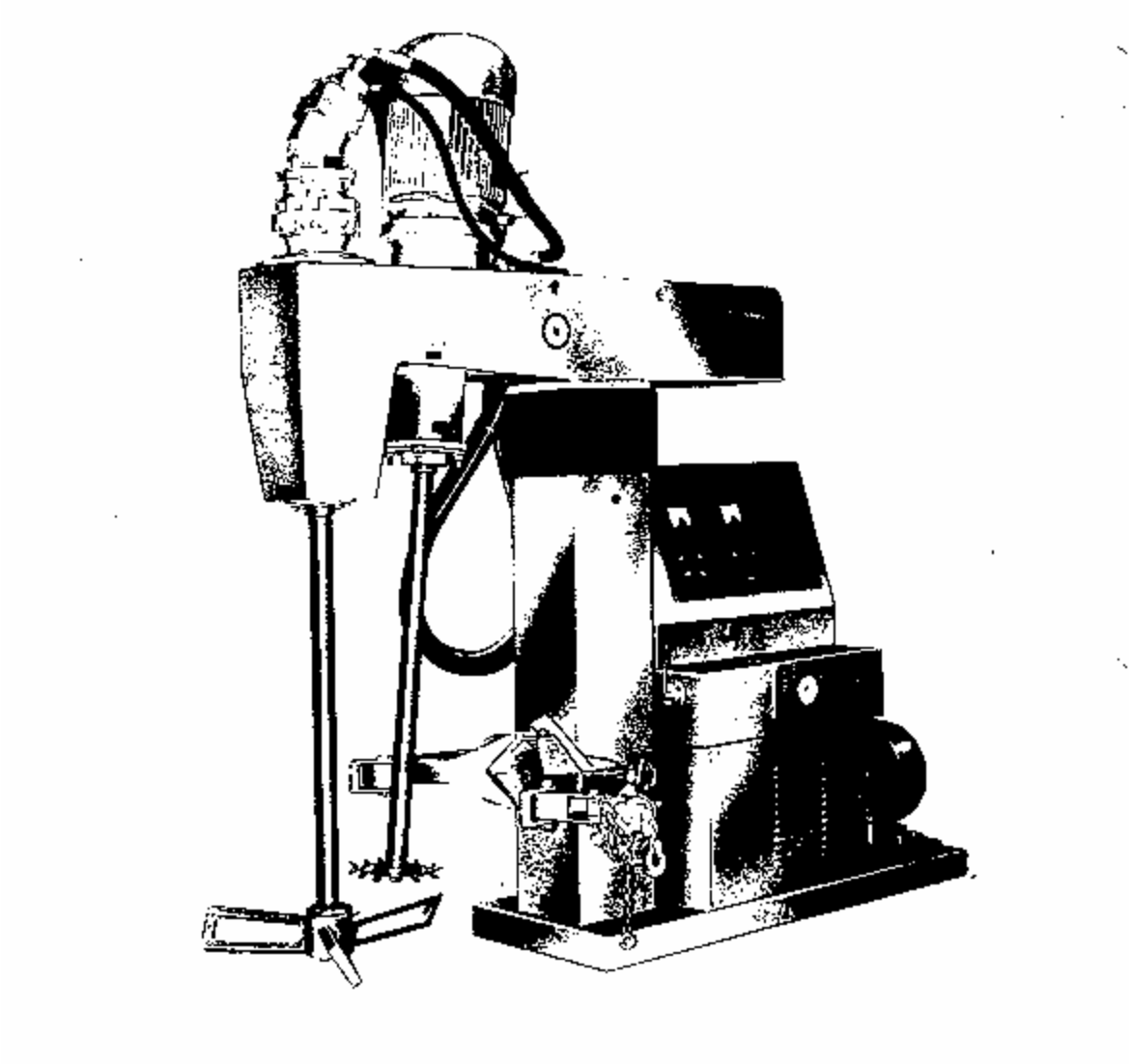
- Compilations of Impeller Numbers
  - Vendors
  - HIM
  - John Smith
  - PostMixing – www.postmixing.com
  - Various papers

MULTIPLE IMPELLERS

- Often multiple impellers are used on one shaft
    - Changing liquid height
    - High aspect ratio
    - Uniformity required near the top – reaction or solids suspension
    - Uniform distribution of energy - fermenters
    - About 80 % of all agitators made by Lightnin have multiple impellers
- Multiple shafts are sometimes used (batch)
    - Material changes with time

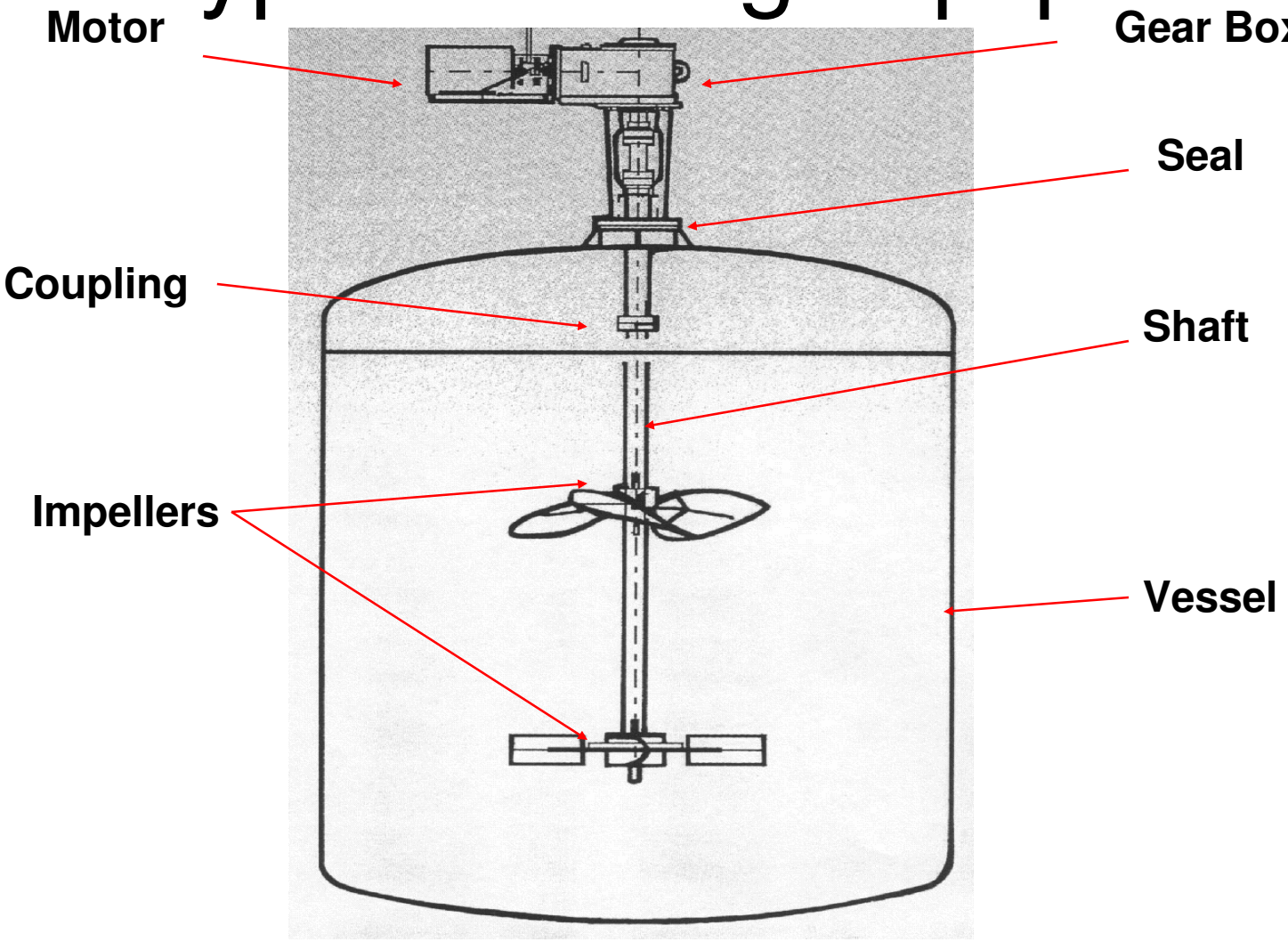
Combination





DUAL BLADE - HIGH AND LOW SPEED DISPERSER

Typical Mixing Equipment



MIXING EQUIPMENT

- MOTORS
  - rotating electrical 1500 to 1800 RPM
- Variable speed
  - old - mechanical
  - new - frequency control on motor
  - constant torque P/N
  - can only go down

MIXING EQUIPMENT

- GEAR BOXES
- reduce speed to more optimum speeds
  - 30 to 100 RPM
- Sturdy clock works
- Built for the use
  - high torques
  - high bending moments

SEALS

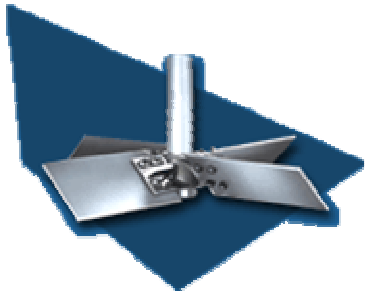
- Keep the contents inside the vessels against pressure through a rotating interface
- Keep the outside from getting in against vaccum
- Rotating and sealing is a challenge
  - High resistance path way
- Packing
- Mechanical seals – single for double
- Can be very expensive – mechanical engineering

MIXING EQUIPMENT

- BAFFLES
- Four vertical
- 1/10 to 1/12 tank diameter
- Off set 1/6 to 1/10 baffle width
- Angled mount
  - small vessel - easy duty
  - Take more power – can cause stagnation

MIXING EQUIPMENT
Flow Patterns

- Radial
  - FBT and Rushtons
- Axial
  - Propellors
  - hydrofoils
  - pitched turbines



AXIAL AND RADIAL FLOW

MIXING EQUIPMENT

- VERY HIGH VISCOSITIES
- Kneaders - batch - horizontal shafts
- Extruders - continuous
  - single screw - pumps
  - twin screws - pumps
  - feeders, melters, pumps, mixers

HIGH VISCOSITY

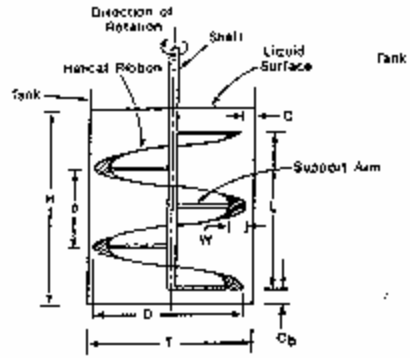
IMPELLERS

* anchor

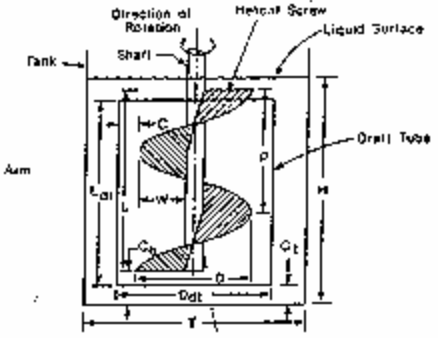
* screw

* single helix

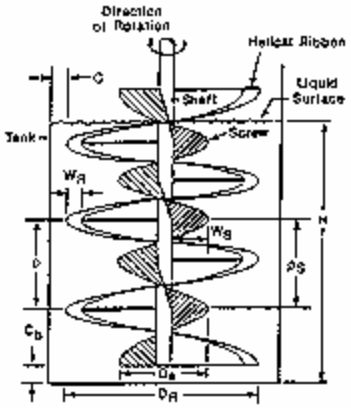
*double helix



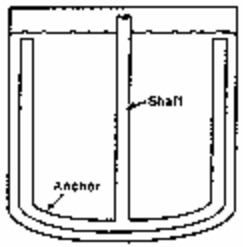
Helical Ribbon Impeller
Showing Geometric Variables
(Helical Ribbon Pumping Down at Wall)



Helical Screw Impeller
in a Draft Tube Showing
Geometric Variables
(Pumping Up in Center)



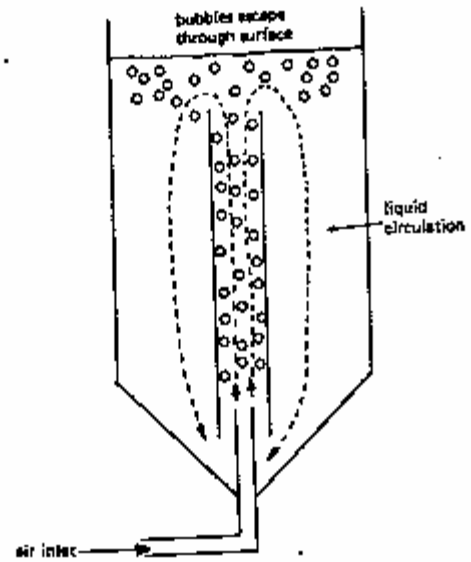
Helical Ribbon Screw Impeller
(Helical Ribbon Pumping Up at Wall
with Screw Pumping Down in Center)



Anchor Impeller

MIXING EQUIPMENT

- Non-mechanical
- TANKS
- jets - eductors
- air sparging
- PIPELINES
- jets
- motionless mixers



TANK MIXING WITH AIR

DRAFT TUBES

- Popular in some continuous crystallizers
- 0.5 TO 0.6 tank diameter
- Work best with fixed liquid level – continuous versus batch
- Give good top to bottom uniformity with only a lower impeller – more regular flow pattern
- Impeller acts as a pump
  - Impeller has a head flow curve
- AIChE Nov 07 meeting – Chemineer presentation – Eric Janz

SPECIAL MIXING EQUIPMENT

- HIGH SPEED DISPERSERS
- HOMOGENIZERS - WHISTLES
- In tanks / vessels and in line
- Colloid Mills
- Agitated Media Mills
  - disperse solids - add a third phase - media

HIGH SPEED DISPERSER

- SAW TOOTH NPO = 0.5

Dynamic In-line Mixers

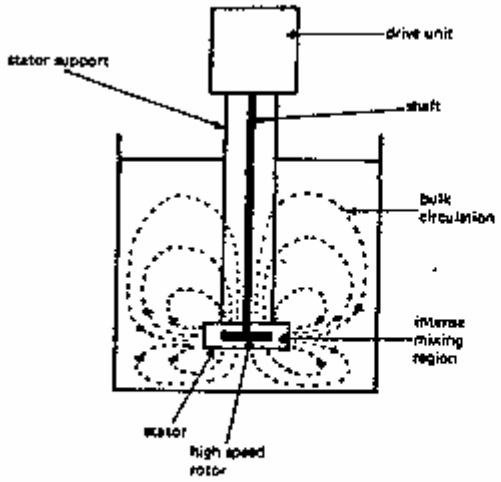
An inefficient pump

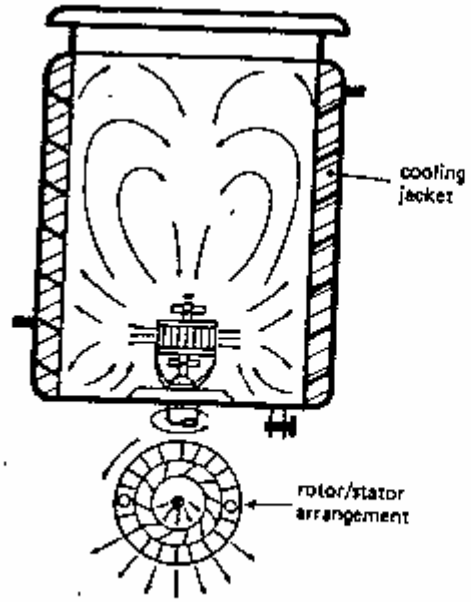
ROTOR STATOR MIXERS

- Many alternate names e.g. colloid mill, dispersator etc.
- Continuous devices or tank type
- Run as once through or on recycle
- Configuration
  - High speed rotor
  - Non-moving stator with perforations
  - Many variations

ROTOR STATOR MIXERS

- Operating parameters
- Tip speed
  - 4000 ft/min or 22 m/s
  - 18000 ft/min or 100 m/s
- Power per unit volume
  - 10 kw/kg


drive unit
stator support
shaft
bulk circulation
intense mixing region
stator
high speed rotor


cooling jacket
rotor/stator arrangement

HIGH PRESSURE HOMOGENIZERS

- Pump fluid up to a high pressure
  - Many atmospheres
- Pump through a nozzle
  - Sometimes with a baffle plate
- Run continuously or batch often with recycle
  - Multiple passes
- Some manufacturers
  - Sonic – sonolator
  - Microfluidics
  - Niro
  - APV Gaulin
  - Premier

MIXING EQUIPMENT

- Multiple Shaft Mixers
- Common in batch service
  - food and cosmetic
  - two or three separate shafts
- Slow speed - anchor - acts as baffle
- Medium speed turbine
- High speed - disperser

GLASS LINED EQUIPMENT

- Particularly popular in pharmaceutical industry
  - As much as 80 percent of reactors
- Glass lining peculiarities
- All entrances through top
- Dip tubes and thermocouples
- Not many openings
- Vertical cantilevered baffles – overhung
- Few if any baffles

GLASS LINED EQUIPMENT

TRANSITIONAL REGIME MIXING

- Relatively new development out of Japan
- Large blade widths and diameters
- Slight angles
- A fair amount of data on Npo and mix time

MAX BLEND

MIXING EQUIPMENT selection

- Desired process result
- Continuous or batch
- Size of volume
  - pipe
  - vessel or tank
- Viscosity, phases, intensity, time

MIXING EQUIPMENT selection

- Many possible mixer selections will give the desired process result
- Secondary considerations determine "best"
  - cost - guidelines
  - retrofit - existing
  - energy - time
  - volume or time

MIXING EQUIPMENT selection

- Most common
- Low to medium viscosity
- Tanks with hydrofoils or turbines
- blending, dispersions, reaction
- batch or continuous
- Avoid special equipment
  - hard to justify

DESIGN VERSUS RATING

- Equations in this course tell how to rate a given design
- Picking a design to rate is the engineering art – experience
- Many designs will work – give the process result
  - Best is relative based on other criteria

COST OF AGITATION

- Investment = torque = power/speed
- Operating cost = power
- Always a balance based on cost of power
- versus value of product/production

GUIDELINES

- Tip Speed
- Power per Unit Volume/Mass
  - turbines 3-4 m/s .2-.6 KW/m3
  - 600 – 700 fpm 1-5 HP/1000 gal
  - HSD 6-27 m/s 10-14 W/KGm
  - 1000 – 5000 fpm
  - Dispersers 20-40 m/s 20-40 W/KGm
  - 4000-8000 fpm 0.2-0.5 HP/gallon
- as scale increases tip speed changes slightly P/V often goes down

UNIT HINT

- ENERGY DISSIPATION
- SI watts/kgm or kwatts/m3 (for water)
- English units Horsepower/1000 gallons
- Turbulence theory suggests
  - Pm - proportional to V^3/ D
    - Where Pm is power per unit mass and V and D are appropriate velocity and dimensions

SCALE UP

- Run small scale experiments to predict large scale performance
- Common question in mixing
- If know enough often can design and do not need scale up
- Will discuss throughout the course
- Will summarize at the end

COMPUTATIONAL FLUID MECHANICS

- A recently developed tool for modeling fluid dynamic situations
- Quite popular in mixing
- Based on solving equations of motion
- Many assumptions – particularly for multiple phase flow
- Will summarize at end.

END M3